Measuring Firm Conduct in Differentiated Products Industries*

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Introduction

A very basic empirical question in industrial organization is the following: which products in a differentiated product market are close competitors with one another. This closeness of competition between two products is determined by the degree of consumer substitutability between them. Thus substitution patterns are the key to many supply side questions of interest. For example, the variation in substitution patterns among the products in a market can be used to study firm "conduct": if there is a high degree of substitutability between the products of rival firms, then markups (and hence prices) should be systematically lower for these products when firms are competing as compared to colluding (Bresnahan 1981, Bresnahan 1987). Furthermore, for any particular hypothesis about firm conduct, substitution patterns drive the effect of counter-factual policy changes on market outcomes, such as mergers, new product introductions, etc.

In this paper, we propose a data-driven methodology to study industry conduct in markets for differentiated products. Our approach is very much in the spirit of the classic conduct

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studies with homogenous goods industries (Bresnahan 1982). We generalize the Bresnahan 1987 strategy for testing competition versus collusion to an environment with potentially rich product differentiation and also allowing for a larger class of possible supply relations to determine firm conduct. This allows us to directly examine how firms internalize market power (arising from product differentiation) in prices, rather than assuming it in the form of stylized game theoretic models such as Bertrand-Nash equilibrium which have become dominant in the literature.

An important ingredient to identify a flexible supply relation function is the availability of instruments varying exogenously the potential markups of products. We show how to adapt the Differentiation IV's proposed in Gandhi and Houde (2019) to this setting. We can use our estimation of the supply relation among firms in a differentiated product industry to test hypotheses about conduct as well as study counterfactuals such as mergers, and allows us to directly link to the outcomes of these counterfactuals to variation in the data.

1 Empirical Application: Demand for Cars

In this section, we revisit the application of Berry et al. (1995), and measure the degree of differentiation between new cars. Our objective is to illustrate the ability of our differentiation IVs in precisely estimating the parameters of a mixed-logit model. While the original application considered both supply and demand moment restrictions, our objective is to propose a class of IVs that can identify the parameters without relying on a particular equilibrium model. In the final section of this proposal, we exploit this feature to propose a simple test of coordinated pricing.

The original model considered by Berry et al. (1995) is a mixed-logit random utility model with standard-normal random coefficients.[1] We consider the same continuous product attributes to describe the willingness to pay of consumers: list price ($1983/1,000), car size (i.e. width $\times$ length /10,000), horsepower to weight ratio, and the number of miles per dollar. We augment the model with additional discrete characteristics: brand dummies, year dummies, air-conditioning, automatic transmission, power-steering, front-wheel drive, four-cylinder, diesel engine. In addition, we estimate a log-linear indirect utility model.

[1]The distribution of the random taste parameter associated with the price variable corresponds to a log-normal distribution estimated using the year-specific income distribution.

Our identification strategy is to construct two sets of instrumental variables to identify the non-linear parameters $\theta = \{\theta_1, \dots, \theta_K,\}$ determining the degree of differentiation between products, and the linear price coefficient β_p allowing us to decompose the average valuation of consumers into a quality and a price effects.

To correct for the simultaneity of prices, we exploit the variation induced by the differential impact common cost shocks on the relative price of cars with different product attributes. In particular, since most Asian and European cars were produced abroad during this time period, changes in the price oil and in exchange rates lead to changes in the marginal cost of selling cars to the US. Similarly, the relative price of bauxite and iron differentially affect large and small cars.[2] We exploit these sources of variation as follows:

$$w_{jt} = \begin{pmatrix} \left(\Delta\text{Gas price}_t, \Delta\text{Exchange rate}_t\right) \times \text{Country of origin}_j \\ \text{Bauxite price/Iron price}_t \times \text{Car size}_{jt} \end{pmatrix}$$

To construct the differentiation IVs, we extend the approach developed in the Monte-Carlo simulations to account for the multi-dimensional nature of product differentiation. In particular, for each continuous characteristic $x_{jt} \in \left\{\hat{p}_{jt}, \text{HP/WT}_{jt}, \text{Size}_{jt}, \text{DPM}_{jt}\right\}$, we construct the histogram of characteristic differences, and the sum of competing product characteristics along six dimensions. More formally, for each distance grid $c_{k,t} \in \{c_{1,t}, \dots, c_{K,t}\}$:

$$N^x_{jt,k} = \sum_{i \neq j} 1(d^x_{ji,t} < c_{k,t})$$
$$\bar{X}^x_{jt,k} = \sum_{i \neq j} 1(d^x_{ji,t} < c_{k,t}) \times X_{jt}$$

where $d^x_{ji,t} = x_{jt} - x_{it}$. To account for the change over time in the distribution of characteristics, we define the histogram cutoffs as the within year percentiles of the distribution of $d^x_{ji,t}$, between $1/(K+1), \dots, K/(K+1)$. In addition, for discrete characteristics such as the A/C and automatic (AT) indicators, we replace the cutoffs with indicator variables equal to one for product sharing the same attribute (e.g., $d^{a/c}_{ij,t} = 0$).

Table 1 present our main set of results. Each entry in Table 1b correspond to a separate single-dimension random-coefficient model. In columns (1) and (2) we compare

[2]To account for the fact that car makers are not price takers in the steel or aluminum market, we replace the two input prices with predicted prices using current and lag oil prices.

the parameter estimates obtained with the instrumental variables used in Berry et al. (1995), and with the differentiation IVs defined above. The results are consistent with the Monte-Carlo simulations. The within-firm summation of product characteristics lead to very imprecise results, similar to the "random characteristic" and Market-IVs discussed above. This is not surprising since those variables only vary at the market/firm level, and are uncorrelated with the degree of differentiation of products.

In column (3), we report the results of each model estimated separately using an approximation of the optimal IV of Chamberlain (1987) proposed by Berry et al. (1999) (see also Reynaert and Verboven (2013)). For each specification we use the first-column results as starting values for $\hat{\theta}$.[3] The use of those instruments successfully eliminate the weakness problem found in column (1).

Importantly, parameter estimates and standard-errors are nearly equivalent to the ones found with the Differentiation IVs. This is not surprising, since our main theoretical result suggest that these instruments contain the same information as the optimal IV discussed in Chamberlain (1987). More specifically, we can use Theorem **??** to show that the conditional expectation of the derivative of the quality assignment is an unknown function of the distribution of the characteristic differences:

$$E\left(\frac{\partial \xi_j(\theta)}{\partial \theta_k}\Big| X\right) = E\left(\frac{\partial \xi_j(\theta)}{\partial \theta_k}\Big| F_j(d)\right) = g_k(F_j(d)) \tag{1}$$

Table 1b confirms this results in the multi-dimensional case. In this specification, we estimate a model with four normally distributed random coefficients. The parameters are very precisely estimated for three of the four variables, and are comparable across both sets of of instruments. Notice that the optimal IV specification is estimated using column (1) as starting values, rather than using the market-level IVs results. Therefore, we do not find efficiency gains associated with using the two-stage approach proposed by Berry et al. (1999)

[3]The optimal IV approximation relies on evaluating the derivative of the quality assignment at $\xi_j = 0$. Since this derivative is zero at $\theta = 0$, we use starting values equal to $\min(0.1, \hat{\theta})$ to construct the moment conditions.

Table 1: GMM estimation results for the car application

(a) Single dimension models

	(1) BLP-IV	(2) Diff. IV	(3) BLP (1999)
$\hat{\sigma}_x$			
Price	2.075	1.373	1.254
	(1.36)	(0.25)	(0.3)
HP/WT	2.916	2.611	2.531
	(6.73)	(0.55)	(0.85)
DFI	25.35	2.472	3.2
	(6.83)	(0.55)	(0.23)
FWD	0	1.896	1.823
	–	(0.23)	(0.25)
Four cyl.	0	2.433	2.523
	–	(0.38)	(0.39)
$\hat{\beta}_p$	-3.909	-3.801	-3.796
	(0.75)	(0.77)	(0.65)

(b) Multi dimension models

	Diff. IVs		BLP (1999)	
	Est.	S.E.	Est.	S.E.
$\hat{\sigma}_x$				
Price	1.11	0.29	1.12	0.31
HP/WT	1.47	0.43	1.53	0.48
DFI	1.21	0.73	1.01	1.57
FWD	1.34	0.18	1.04	0.17
$\hat{\beta}$				
Price	-16.04	0.75	-15.48	0.40
HP/WT	-0.03	0.35	-0.39	0.22
DPM	-0.14	0.20	-0.16	0.19
Car Size	1.38	0.73	1.79	0.50
DFI	-0.36	0.19	0.18	0.14
FWD	0.05	0.08	0.06	0.07

2 Market conduct in differentiated product industries

In this section, we describe a general framework to exploit variation in demand elasticities as an "instrument" to test and estimate firm conduct. It has been typical to assume very stylized models of firm conduct in empirical work, most notably Bertrand-Nash equilibrium. Yet there is very little direct evidence to support these hypotheses nor systematic investigation of alternatives that are estimated by actual firm behavior. In this section, we propose an identification and estimation strategy to study market conduct in differentiated product industries. We analyze the U.S. automobile as a case study, and construct a reduced-form test for coordinated pricing.

The detection and measurement of coordinated pricing in differentiated product industries was first analyzed in Bresnahan (1981, 1987), in the context the 1950's U.S. car industry. The main insight from this analysis is that the hypothesis of coordinated pricing can be tested by studying the relationship between prices and the elasticity of substitution between products.

Assuming that the marginal cost of selling each product is independent of characteristics of other products, the Bertrand-Nash equilibrium implies that two products that closely compete for the same consumers will exhibit low prices, relative to their own quality levels. This comparative static prediction produces a simple testable hypothesis: under Bertrand-Nash pricing, conditional on quality levels prices are increasing in the degree of product differentiation. The "closeness of competition" must be inferred from cross elasticities of demand and it is therefore crucial to be able to identify the parameters of the demand model without relying on supply-side restrictions, which our previous analyses accomplished.

More generally the following supply relation is consistent with a large class of equilibrium models:

$$p_j = \text{mc}\left(x_j\right) + \text{markup}_j \quad j = 1, \ldots, J. \tag{2}$$

Very much like the quality assignment function from the demand side, the markup of product j is an unknown function of the distribution own and cross demand elasticities (D_j), and of "ownership structure" determining to degree of market coordination (Ω_j). This ownership structure is the differentiated-product analogue of the "conduct parameter" used to measure market power in homogenous product industries.[4]

[4]See Bresnahan (1989) for a review of this literature.

Rather than assuming a specific conduct, our approach is based on estimating a reduced-form approximation the supply relation:

$$\text{markup}_j = \mu(D_j, \Omega_j) \approx \sum_l \pi_l m_l(D_j, O_j) \tag{3}$$

where O_j is the observed ownership matrix, and $\{m_l(D_j, O_j)\}_{l=1,\dots,L}$ a L-dimension vector of moments characterizing the joint distribution of (D_j, O_j).

While the exact market conduct is unknown, most data-sets include detailed information of the joint ownership of products. Researchers might also have multiple dimensions characterizing the (unknown) conduct of firms, and therefore can use multiple variables characterizing the possible conducts. For instance, joint-ventures, or multi-market contacts can be described by multiple "ownership matrices". In this case, O_j will be a matrix, rather than a vector of zeros and ones.

Assuming that the marginal-cost can be approximated by a linear function of observed characteristics, we can write the reduced-form supply-relation as follow:

$$p_j = x_j c + \sum_l \pi_l m_l(D_j, O_j) + \omega_j. \tag{4}$$

This equation can be estimated using prices, market shares, and product characteristics data. The substitution matrix D is itself a function of observable characteristics and the estimated demand parameters, while the observed ownership matrix summarizes the set of possible market conducts. However, this equation cannot be estimated directly by OLS, since D_j is endogenously determined with prices and market shares. In order to identify a reduced-form pricing equation, we therefore face a similar simultaneity problem, and require further assumptions on the distribution of ω_j.

Following Bresnahan (1987) and Berry et al. (1995), we assume that the marginal cost of each product is independent of the characteristics of competing products and the observed ownership structure:

$$E\left[\text{mc}_{jt} | x_{1t}, \dots, x_{Jt}, O_j\right] = E\left[\text{mc}_{jt} | x_{jt}\right]. \tag{5}$$

This assumption is analogous to our earlier assumption that the willingness to pay for each product is function of its characteristics, and independent of attributes of other products available in the market. It can used to construct instrumental variables correlated with the reduced-form functions $m_l(D_j, O_j)$. In particular, the Differentiation IVs interacted with the ownership matrix are correlated with the elasticity of substitution between products, and therefore valid instruments.

Estimating the parameters of the reduced-form supply relation is useful for at least two reasons. First, we can use $\{\hat{c}, \hat{\pi}\}$ to test assumptions of alternative conduct models. In the following subsection, for instance, we test the null hypothesis that multi-product firms internalize substitution patterns when setting the prices of substitutable products. Second, we can use the estimated function to simulation counter-factual experiments that change market structure. While such simulation can lead to erroneous predictions when inducing *large* market-structure, it can provide a valid and robust method to simulate *local* changes such as prospective mergers or the entry of a new product. See Benkard et al. (2013) for similar approach to merger evaluation.

3 Testing for coordinated pricing

We provide an example of using the above framework to construct a reduced-form test that prices are coordinated within firms - one of the central features of the Bertrand-Nash model. In particular, we test the hypothesis that the effect of the cumulative diversion ratio within firm has a zero effect on prices, while the cumulative diversion ratio across firms has a negative effect on prices. These two hypothesis can be tested by estimating the following reduced-form pricing equation:

$$\ln p_{jt} = x_{jt}c + \lambda_1 \ln C^F_{jt}(r) + \lambda_2 \ln C^{-F}_{jt}(r) + \omega_{jt}, \tag{6}$$

where $C^{-F}_{jt}(r)$ is the cumulative diversion ratio among products controlled by competing firms, and $C^F_{jt}(r)$ is the cumulative diversion ratio among products controlled by the same firm. If firms set prices across their portfolio of products to maximize their joint profits, the effect $C^F_{jt}(r)$ should be zero. In contrast, if firms on average fail to coordinate prices *across* companies the effect of $C^{-F}_{jt}(r)$ should be negative. We compare the results with two concentration measures: closest competitor ($r = 1$) and ten closest competitors ($r = 10$).

Table **??** presents summary statistics on the distribution of cumulative diversion ratios,

Table 2: Coordinated pricing test result

	(1) OLS	(2) OLS	(3) IV	(4) IV
$C^{-F}(1)$	-0.18[a]		-0.09[a]	
	(0.01)		(0.02)	
$C^{F}(1)$	0.0004		0.008	
	(0.003)		(0.00863)	
$C^{-F}(10)$		-0.22[a]		-0.11[a]
		(0.02)		(0.03)
$C^{F}(10)$		0.001		0.005
		(0.003)		(0.009)
R^2	0.926	0.928	0.922	0.923

as well as on the residual demand elasticity, and on the implied markups under the hypothesis that prices are generated from a multi-product Bertrand-Nash pricing equilibrium.

The diversion ratios suggest that competition is fairly localized in the car market. Although substitution to the outside option is probably too important (nearly 60%), more than 50% of the "inside" substitution is going towards the ten closest substitutes, as measured by $\text{CR}_j(10)$. In contrast, the multinomial logit model implies nearly uniform diversion ratios of about 0.07%, and a much larger substitution towards the outside good ($\text{DR}_{j,0} = 90\%$).

In order to estimate (6), we instrument for the "own" diversion ratios by measuring the average distance to the products owned the same firm (along the three continuous dimensions), and instrument for "other" diversion ratios using the differentiation IVs used to estimate the demand model.

The results of this exercise are presented in Table 2. The estimates of λ_1 provide strong support for the hypothesis that car makers successfully coordinate prices across models in order to internalize the externality created by substitution patterns. The effect of $C_{jt}^{F}(r)$ is zero across all specifications, with or without instruments.

In contrast, the effect of $C_{jt}^{-F}(r)$ different from zero, both statistically and economically. The 2SLS results suggest that a 10% increase in the diversion ratios to the closest competing products lead to a 1% increase in car prices. Since the standard deviation of the cumulative diversion ratios are between 60% and 70% of the averages, we can infer than a one standard-deviation increase in the degree of differentiation leads to 6 to 7 percent price increase.

Although the magnitude of these effects does not provide support for a particular conduct model, it allows us to reject the hypothesis that firms were perfectly colluding.

Interestingly, the comparison of the OLS and 2SLS estimates highlight the importance using instruments to estimate these supply relationships. The results show that the simultaneity of the elasticity of substitutions with respect to the unobserved cost-shocks lead to an *over-state* the importance of price competition between companies. The coefficient estimates show that the effect of product differentiation on prices is more than double in the OLS specification, relative to the 2SLS specification.

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